International Journal of Advanced Engineering, Management and Science (IJAEMS)
Peer-Reviewed Journal
ISSN: 2454-1311 | Vol-8, Issue-7; Jul, 2022
Journal Home Page: https://ijaems.com/
Article DOI: https://dx.doi.org/10.22161/ijaems.87.3

Review on Hydrodynamic Modelling of Desalination Plants Brine Effluent Marine Outfalls

Yasser Elsaie[1], Hoda Soussa[2], Mohamed S. Gado[3], Ahmed Balah[4]

[1]Associate Professor of Coastal Engineering and Shore protection, Head of Civil Engineering Department the Higher Institute of Engineering Elshrouk City Cairo, Egypt.
[2]Professor of Water Resources Engineering Faculty of Engineering, Ain Shams University, Cairo, Egypt.
[3]Teaching Assistant at The Higher Institute of Engineering Elshrouk City Cairo, Egypt, Phd Student, Irrigation & Hydraulics Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.
[4]Assistant Professor, Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

Received: 12 Jun 2022; Received in revised form: 09 Jul 2022; Accepted: 13 Jul 2022; Available online: 17 Jul 2022

***Abstract*— *This paper presents a review on hydrodynamic modelling of desalination plants brine effluent marine outfalls. Brine effluent is a byproduct of desalination plants that must be safely discharged with little environmental impacts. Several researchers have been studying the behavior of brine effluent disposal to the sea using marine outfalls but due to its complex behavior yet it is not completely understood, where the international design standards and specifications are limited and there is no unified design approach for the marine outfalls. The dilution and dispersion ability of the ambient water body are discussed. The outfall inclination angle and current speed are also investigated.*

***Keywords*— Hydrodynamic modelling, Brine effluent, Marine outfalls, Dilution.**

I. INTRODUCTION

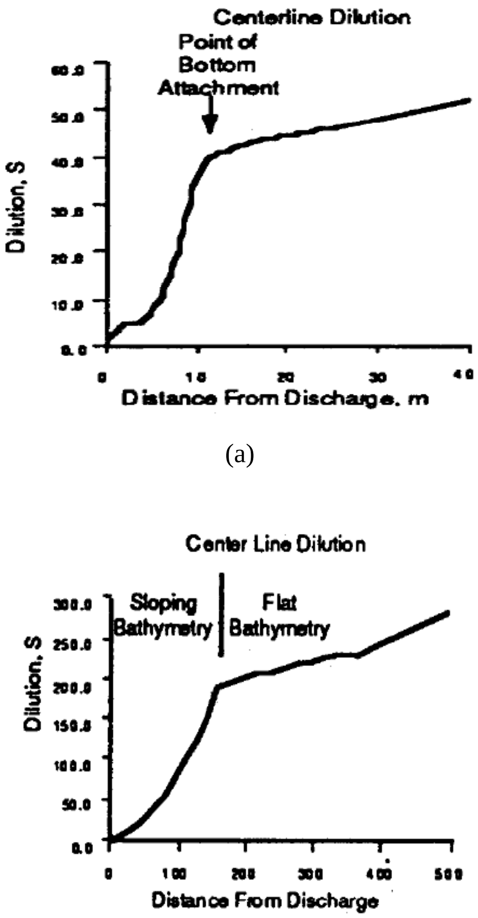
One of the major pillars for maintaining human and other biological life on earth is the availability of water. In most arid, and semi-arid coastal zones, water demand is rising for the urban and industrial sectors, forcing planners to find new, alternative, and renewable water resources. Additionally, because fresh water sources are so far away from coastal communities, bringing fresh water there is exceedingly expensive and complicated. The desalination process has emerged as one of the most viable and promising alternatives for supplying fresh water to numerous industries, particularly those in water-stressed locations such as coastal areas. Brine effluent is a byproduct of desalination technique that must be safely discharged with little environmental impacts. This hyper saline water is discharging to the marine environment using outfalls in a turbulent jet form with density higher than the density of the receiving water body which more the allowable limit 10 %. The design of marine outfalls has not been coved yet and there is a need to have a unified design approach for these outfalls that leading to safely discharging of hyper saline water from desalination plants.

II. PREVIOUS STUDIES

J.V. Del Benel et all (1994) [1] used CORMIX software to study the effect of brine discharge to ocean and the results showed that dense brine discharges can impact the benthic environment. An effluent dilution to 1 ppt above ambient is a conservative guideline for initial studies to limit the impact of brine effluent to the ocean. Dilution of dense brine effluents to 1 ppt in reasonable distances can be achieved. The CORMIX software can be used to predict the dispersion of brine discharges as shown in fig 1 (a), (b).

Vlado Malacic (2001) [2] Conducted a numerical model to study the initial dilution of sewage discharging from a diffuser into stratified waters in the Bay of Piran northern Adriatic. Simulation of model results to the initial inclination of a buoyant jet has low influence on dilution, but a high influence on rise height. On the other hand, the discharge velocity has a relatively low impact on the rise

height, but affects the dilution much more. The model also showed that in a calm sea with typical summer stratification, plumes, which emerge from orifices spaced at 10 m, remain well separated until they reach a layer of neutral buoyancy below the sea-surface.



(a)

(b)

Fig. 1. dilution with downstream distance for submerged (a) and Surface (b) discharge.

Merih Ozcan, and Dr. K. Tunc Gokce (2002) [3] Made Numerical model using MIKE21 for case study outfall design in turkey to evaluate the pollution effects of the imposed water quality. For estimating effluent dilution average current speed value is used at many outfalls design. Choice of those average values depend on random observations that are usually inadequate in terms of monitoring duration and number of samples. For model calibration limited period of 4 weeks total duration field measurements at 4 different locations around the discharging outfalls were mainly observed. MIKE21 advection-dispersion model was coupled with CORMIX. firstly, the initial dilution and near field temperature gradient calculated by CORMIX, then the results were transformed into MIKE21 for far-field modeling. Using numerical models are a very lately started in outfall design projects in Turkey. The results showed that with the usage of numerical modeling, it may be viable acquiring greater records at the oceanographical situations of the layout place even if the sphere facts are limited.

Thomas Hoepner*, Sabine Lattemann (2002) [4] A field study for desalination plants chemical impacts at the northern Red Sea was made to present unique transferable results. Brine consists of many hazardous compounds such as chlorine, copper, and antiscalants additives That, have various environmental fate. Effects of chlorine and copper will appear near to the outlets, then diminished due to chlorine dilution, and copper transport into sediments. However, concern from these compounds must still be expressed due to high toxicity of chlorine, risk associated with copper enrichment in sediments, but low environmental risk of antiscalants from MSF and RO plants. Because of negligible terrestrial runoff at the Red Sea especially at north antiscalants has a major drawback of poor degradability that requires more investigation. Due to its geographical isolation, the Gulf Aqaba one of the most sensitive sites for brine effluent, leaving pollutants with little diffusion and adversely affecting marine life and habitats. The Arabian Gulf has installed seawater desalination capacity about 7 million m3/d, equal half of worldwide capacities. The Arabian Gulf has more favorable flushing conditions than the Red Sea, and the plants receive feed water from a water body, which is under the influence of the upstream plants in the Red Sea. The risk of ecosystems damage in close to plants outlets is at hand. However, landfill activity a has more imminent consequences that destroys the shallow water as described in Tarut Bay.

The Red Sea must be considered a unique ecological treasure that is vulnerable to ecological damage. So that, information maps about plant locations can be developed that are an effective tool in environmental impact analyses.

Anton Purnama et all (2003) [5] developed a numerical model to simulate the dispersion of brine discharges from a coastal desalination plant at Oman. Coastal desalination plants in Oman discharge the brine waste containing excessive salt awareness into the sea. Continuously discharging brine wastes immediately at the coastline will bring about the salinity expanded alongside the coastline. The effect of brine disposal operations on coastal and marine environments may be prevented with the aid of using extending the outfalls in addition offshore to the sea.

Y. Fernandez-Torquemada et all (2005) [6] Made an experimental study to present the monitoring, on time and space, of the brine discharge originated by the Alicante seawater desalination plant (SE Spain) for the reverse

osmosis (SWRO) desalination plant started to operate in September 2003, to the date of study. Three surveys have been done in February, April and August 2004. In each campaign a grid of more than 100 sampling stations near the brine discharge place was established, with the purpose of delimiting the brine plume and its dilution along the area. At each station salinity measures were taken from surface and bottom water with a measuring range of 0 –70 psu and a resolution 0.01 psu. After the results of the first survey, the grid was extended to cover a larger area. An interpolation of the data obtained in each campaign was made using the kriging technique. Geostatistical Environmental Assessment Software program developed by the (USEPA) was used. One year after the plant operation, the results obtained at these campaigns have shown that dilution of the brine may be lower than the usually accepted and it may affect significant extensions of marine communities. the information obtained in this work can be considered really useful for its application to future similar projects in the Mediterranean Sea.

A.M.O. Mohamed et all (2005) [7] Study the groundwater resources degradation in the eastern region of Abu Dhabi (Al Wagan, Al Qua'a and Um Al Zumool). They made a questionnaire for the surveyed plants to obtain data about the quality and quantity of groundwater, brine and pond water. Furthermore, he analyzed water samples for the three plants, and collect Soil samples from Al Qua'a disposal site and two nearby locations. Water samples were analyzed for physical, chemical and total petroleum hydrocarbons (TPH), soil samples were analyzed for physical, chemical and mineralogical composition. No groundwater samples from surrounding areas were collected.

The results showed that

1. disposal of brine to unlined pond or pits can pose a significant problem to soil and feed water because the risk of saline water intrusion into fresh water increase.

2. Percentages of reject brine from the three plants varied between 30 and 40%. Chemical analysis showed a slight increase in the concentration of salts and EC level that easily reaching the groundwater.

3. TDS concentration about two-fold higher than the feed water supply. Water samples from Um Al Zumool RO plant showed an increase in TPH and electrical conductivity, whereas the highest level of TPH Al Quaa plant.

4. TPH increase in desalinated water can pose a significant health risk.

Alameddine, M. El-Fadel (2006) [8] Developed a model using CORMIX to simulate the dispersion of the brine plume in marine environment by considering heated effluent from a desalination-power plant in Gulf region. For this purpose, the brine characteristics, potential impact, operating conditions, and hydrodynamic characteristics of the area were reviewed. Various simulation scenarios for surface discharge, single, and multi-port diffusers were assessed to determine the optimal outfall structure.

Brine disposal has the potential to degrade the physical, chemical and biological characteristics of the receiving water body. The degree of degradation is highly dependent on the total volume of the brine, dilution rate, and the receiving water characteristics. The environmental effect of brine is also depended on the configuration of the discharge outfall. Gulf area have the large number of desalination and power plants in the world generating about 15,000 MW of electric power and 11.99×10^{6} m3/day of desalinated water. The seawater of the Arabian Gulf differ from the world's ocean waters such as high salinity levels and high temperature that could exceed 45°C.

The CORMIX – GI model was used to simulate the brine plume resulting from the continuous discharge of MSF desalination and power plant. CORMIX is a United States Environmental Protection Agency (USEPA) approved simulation and decision support system that has been adopted for assessing the environmental impacts resulting from point source discharges within their mixing zones. Three basic scenarios to study the mixing behavior and efficiency of surface, submerged single-port and multi-port outfalls into shallow waters typical of the Arabian Gulf, were conducted. Results showed that Simulations of the brine plume dispersion from a desalination-power plant in the Gulf region revealed the inadequacy of using surface discharge outfalls for brine disposal. Using multi-ports proved to be adequate to enhance dilution rates and limit the potential environmental impacts, whereby a tenfold dilution rate was achieved within a 300 m mixing zone as shown in figs 2,3.

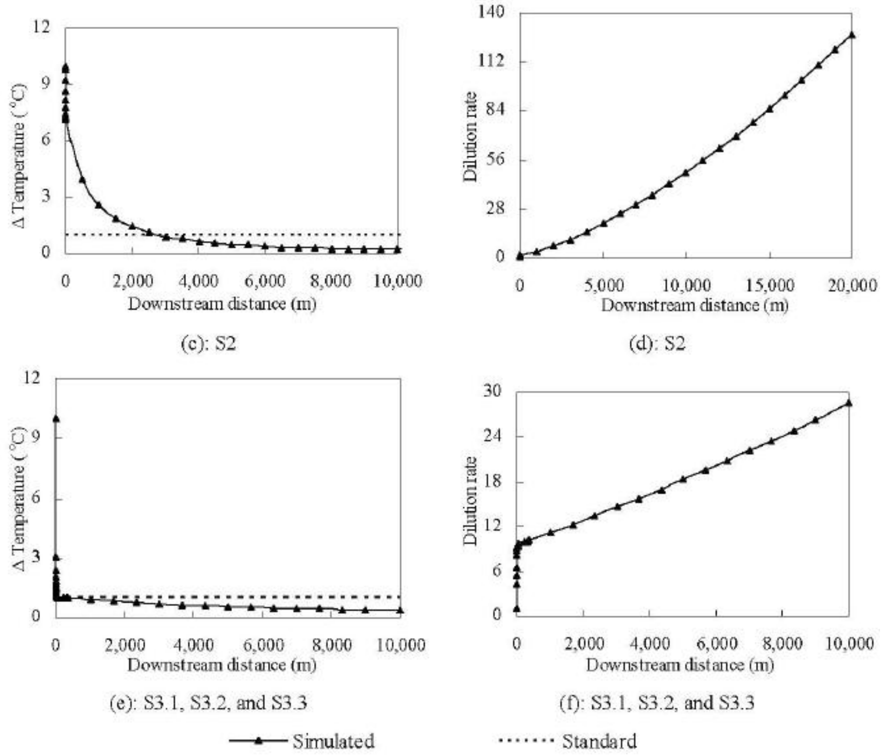


Fig. 2 Temperature drop and dilution rates with downstream distance for different simulated scenarios.

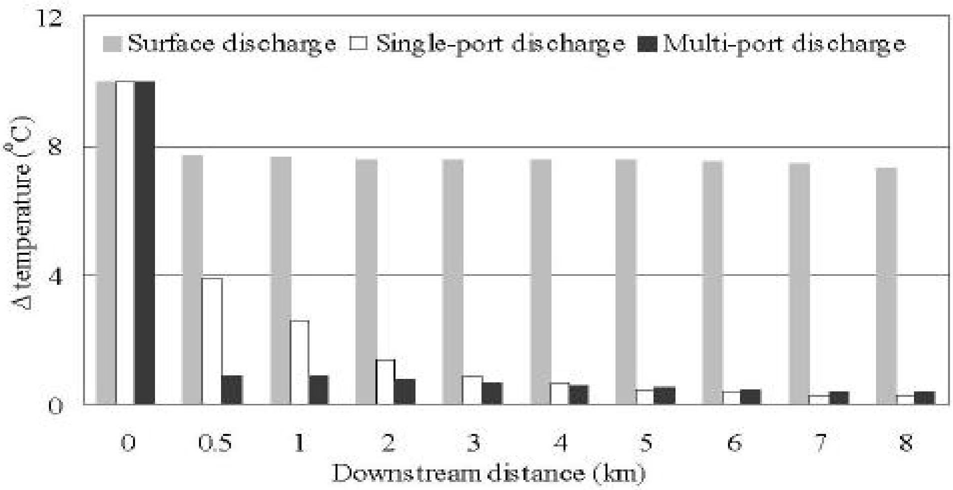


Fig. 3 Plume temperature drop Comparison between surface, single and multi-port discharge.

Haibo Niu, et al. (2007) [9] The PROMISE model has been developed to supply a tool for probabilistic analysis of the mixing of produced water in the marine environment. They describe the validation of the near field module of PROMISE against laboratory data and other models. The model predictions on buoyant jet trajectory, plume width and dilution have been checked against three types of buoyant jets from three different data sources. Statistics on the predicted versus measured values have been obtained. The results show that PROMISE can provide satisfactory prediction in all three parameters and the degree of bias is comparable to other models. The mean errors of PROMISE predictions are slightly smaller than other models but most of the ranges of its prediction errors are slightly wider than that of other models.

H.H. Al-Barwani*, Anton Purnama (2007) [10] To explore the environmental impact and how we may reduce it, a mathematical model of brine plumes discharged into seawaters using a two-dimensional diffusion equation were constructed. Because the tidal current dominates the flow in

the sea, the brine effluent will be transported away from the outfall, and then will be returned to the outfall when the flow reversed. It's possible that the plume returned to the outfall three times before finally departing it. Due to constant rate continuous discharge, then the near field coastal water at the reversal flow, when the flow speed and dispersion drops to zero will have an unacceptable high concentration salinity.

Generally, because of a lack data on the impacts of desalination plants on the marine ecosystem to evaluate these impacts for regulatory and design purposes. Higher salinity expected near the outfall, and plume drifting along the coast has been observed. Environmental risks can be reduced by limiting brine levels using several treatment techniques or by assuming maximum concentration limit and the effect of oscillating tide flow on mixing brine outflows should be investigated using a two-dimensional diffusion equation. Maximum concentration on the beach remains constant throughout the tidal cycle, that can be used as an impact measure. Finally, Xmax is observed as a long distance downstream the outfall, increasing as the values of model parameters increase, Cmax can be expressed as

$$\text{Cmax} = \frac{\alpha}{X_{max}+\cos T}\sqrt{\frac{8\pi\eta}{e}}\,. \quad (1)$$

Cmax maximum concentration, α = 0.4, T = π and 2π of a tidal cycle.

Kikkert et al. (2007) [11] developed an analytical solution to predict the behavior of inclined negatively buoyant jets and reasonable agreement was obtained with measurements for initial discharge angles ranging from 0 to 75 deg and initial densimetric Froude numbers from 14 to 99.

Blue Hill Hydraulics Incorporated (2007) [12] developed a CORMIX hydrodynamic model to calculate the size of the thermal plume produced by the Calvert Cliffs and to calculate liquid effluent dilution factors as shown in fig 4. The results showed that 0.5 C more than ambient temperature at the end of mixing zone. The calculated dilution time assumes that the plume is not well-mixed 50-miles from discharge point, therefore, conservative, because it does not include the effect of tides which could increase mixing. According to this analysis the plume does not contact the shoreline of the Chesapeake Bay.

Esperanca Gacia et all (2007) [13] made a field study to study the impact of the hypersaline water on ecosystems. This study conducted in the Mediterranean to study the effect of brine on a shallow Posidonia oceanica meadow for more than 6 years. Posidonia oceanica proved to be very sensitive to both eutrophication and high salinities derived from the brine discharge. The results show that under field conditions Posidonia oceanica is very sensitive to brine discharges from desalination plants. The study concluded that salinity above 39.1 has an impact. Therefore, care should be taken to dilute brine considerably, before it reaches seagrasses in order to preserve these ecosystems.

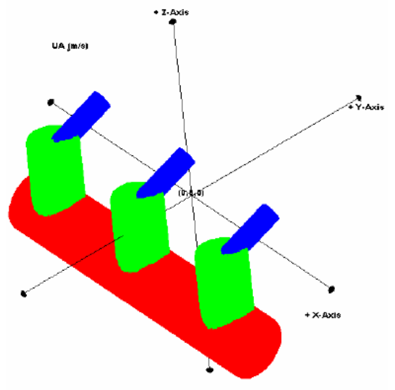


Fig 4. Diffuser configuration

Jochen Kämpf (2009) [14] Conducted a high-resolution three-dimensional hydrodynamic model to explore the mid-field dilution of blended desalination brine discharged into a tidal sea. The model was forced via a salt flux distributed over a given initial mixing volume and ignored any other sources of turbulent mixing such as storm events, residual circulations, or wind waves. The results showed that:

1. While reducing salinity impacts, the blending method can lead to a decrease of dilution in the vicinity of the discharge location, which can pose harm to the marine benthos inside the mixing zone.

2. The blending method leads to decreases of both the horizontal extent of the mixing zone and the degree of vertical density stratification of the water column. This lowers the risk of formation of saline underflows and supports mixing by other influences.

3. The increase of discharge rates might lead to an alteration of the mixing efficiency of diffusers.

A. Etemad-Shahidi, et al. (2010) [15] Using numerical models to predict the plume behavior of heated water discharged from outfalls is an effective method of disposal in coastal areas. This process requires multi-port diffusers. This study developed an application of artificial neural network model for prediction of initial dilution of multiport tee diffusers. Several networks with different structures were tested using error back propagation algorithm. Results of statistical error measures showed that a three-layer network with 9 neurons in the hidden layer is skillful in prediction of initial dilution and the outputs are in good agreement with experimental results. The sensitivity analyses showed that the width of the equivalent slot of the diffuser is the most important parameter in the estimation of initial dilution.

P. Palomar et al. (2012) [16] predicted a numerical modelling based on data obtained from previous studies to improve the design and modelling of brine discharges outfalls, improve the numerical model's ability in the assessments of desalination projects environmental impact. The results showed that CORMIX1 and CORMIX2 employ relatively simplified formulas and are not valid for negative buoyant discharges, then the usage of CORJET, UM3 models is advised more for single port discharges.

Hesham El-Badry et al. (2012) [17] Delft-3D used for preparing hydrodynamic model to the Gulf of Aqaba to estimate the adverse effects of brine effluent disposed from desalination plants on the marine environment in the Gulf. The model is not quantitatively calibrated, but it is qualitatively verified since the present condition results reveal that primary eddies are formed along the centerline of the Gulf which are in line with former studies made by others. The model reproduced the thermal stratification in summer (July) about 6°Cexists between the warm surface layer and the cool deep water from 28°C to 21°C.

Model results showed that observed current speeds at the Gulf sides are larger than at the central part. The Gulf north end has 2 - 3 cm/sec current velocity. Nearest the seabed current velocity found to be larger than at the surface that reveals density current was found due to disposed brine. The model results need to be analyzed by marine ecologist to assess the potential impacts on the marine environment in the GOA. The GOA hydrodynamic model is still in early phases development, the model requires extra effort for enhancements. The current version of the model did not consider the surface heat fluxes due to lack in meteorological observations.

Candela Marco-Méndez, et al. (2012) [18] Conducted a numerical study for Nuevo Canal de Cartagena (Spain) desalination plants, that discharge hypersaline effluent through a submarine outfall pipeline, creating a negatively buoyant brine jet. Many near-field mixing models are used in the prediction and management of brine discharges, but they have rarely been compared with field salinity measurements obtained directly inside the brine jet. Two divers obtained these field measurements and compared them with CORMIX1, CORJET, MEDVSA and UM3 mixing zone model predictions. In general, each model was quite conservative in its results, except UM3, whose prediction presented the best approximation to measured data. It is concluded that direct field measurements should be essential when testing the accuracy of current models or developing new near-field mixing models.

Yasser Shawky et all (2012) [19] Conduct a physical model to study the effect of banha thermal plant outfall on El-Rayah El-Tawfiki. High temperature decreases oxygen concentration in the water which is very important for aquatic life. This phenomenon will be critical in study area with the construction of Banha Power Plant. A physical model was built for designing the intake/outfall to meet with the Egyptian regulations. With using open channel for discharging cooling water 4500 m2 around the outfall has 5^° c above the ambient temperature, that led to dissolved oxygen value less than 7 mg/L which considered a critical value. With using 24 nozzles multi-port outfall the mixing process improve that led to only 600 m2 with raised temperature to 5^° c that considered a small area with low effect on the aquatic live.

CARLOS PALACIO, et al. (2013) [20] The dilution, trajectory and thickness of the buoyant plume formed by wastewater discharge from the submarine outfall of Santa Marta were determined using a near field dilution model and hydrographic data from salinity, temperature and density profiles, as well as from the velocity data at different levels of the water column. The magnitude of the velocity was provided by previous runs of a three-dimensional hydrodynamic model. The results showed that the plume goes through alternating periods of entrapment in the water column or reaching the water surface, according to conditions of upwelling and stratification of the receiving body of water. When the plume comes to the surface, dilution levels greater than 100 are achieved, sometimes up to 400 are reached. When the plume comes to the surface of the water, its thickness varies between 5 and 20 meters. In this scenario, the plume reaches the surface in a diluted form. When the plume reaches the level of neutral buoyancy by entrapment due to stratification of the water column, dilution has the maximum value of 10:1. In these cases, the plume remains trapped at depths between 25 to 47 meters without affecting the surface of the water.

Sami Maalouf et all (2014) [21] Study the optimal design of RO brine outfall for a desalination plant located 168 miles south of San Francisco using CORMIX. They confirmed that marine outfalls with multiport diffusers, if used properly, are very efficient in maximizing dilution levels of negatively buoyant plumes. They also demonstrated that optimization techniques by numerical models can be applied to minimize the total costs of these outfalls. CORMIX is capable of directly performing SWRO brine flow simulations and analyzing nearfield mixing processes. Their findings show that it is possible to build cost-effective marine outfalls that maximize dilution levels while also confirming that all environmental standards and laws are met. The model has an excellent match with the CORMIX output.

D. V. Salgueiro et all (2015) [22] The thermal effluent dispersion from a power plant in Portugal, which collects

water for cooling and subsequently discharges it at a 10 ºC temperature increase, was studied using the (MOHID) 3D hydrodynamic model. During August and October of 2013, a simulation was run with north and south winds as shown in figs 5,6. The results showed that temperature increase is decay from 10 ºC near the outlet to 2 ºC at 2 km away from the outlet.

Wind direction and tide play a substantial effect on plume dispersion, according to model simulations. Under north wind dominance, a well-mixed plume is visible, as contrast to a limited wider plume under south wind conditions that can led to more efficiency losses for the power plant operation, since the water at the intake is continuously warming.

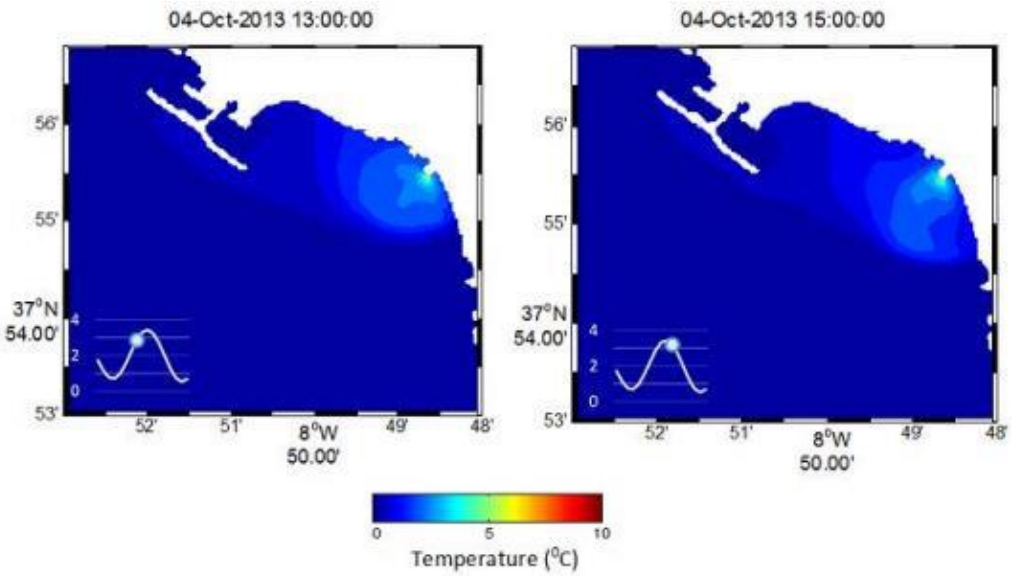


Fig 5. Sea surface temperature profile for cooling water discharge in coastal area, subjected to south wind scenarios.

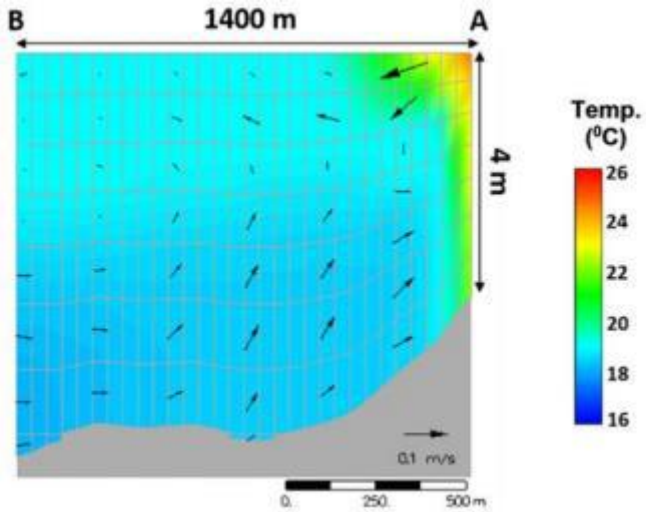


Fig 6. Sea surface temperature profile for cooling water discharge in coastal area, subjected to north wind scenarios.

Ahmad Rezaee Mazyak et al. (2018) [23] Made a simulation by CORMIX model as shown in fig 7 to the outfall pipeline of SAKO desalination plant in the persian gulf Iran which has daily productivity of one million m3/d. The excess salinity in a 200-meter radius around the outfall should be less than 10% of the ambient salinity, according to the environmental regulation. According to near-field model results, the salinity increase at 18 metres from the outfall will be roughly 4.17 PSU, which is less than 10% of the ambient salinity as shown in fig 8. As a result, the environmental criteria are fully met.

Mazen Abualtayef et al. (2019) [24] Used the CORMIX v 9.0 to made a numerical simulation to the brine effluent outfall of Deir Al-Balah desalination plant to study the dilution and dispersion behavior of effluent brine through eight disposal systems such as: single port outfall, alternating multi-port diffuser, unidirectional multi-port diffuser and staged multi-port diffuser. The simulation

results for various outfalls configurations show that the fanned-out unidirectional multi-port outfall is the optimal design configuration, that can meet the disposal standard in the worst ambient condition at the edge of mixing zone to less than 1.25% above seawater salinity as shown in figs 9,10,11.

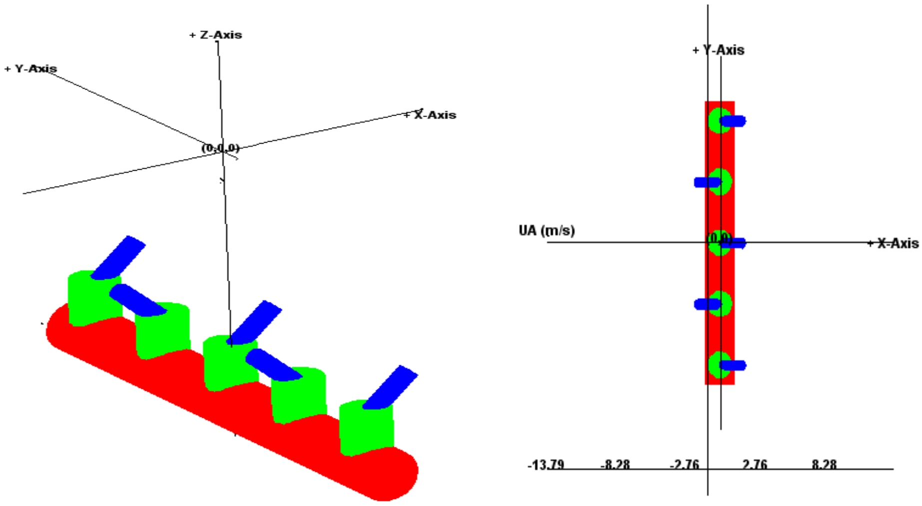


Fig 7. Arrangement of multiport diffuser.

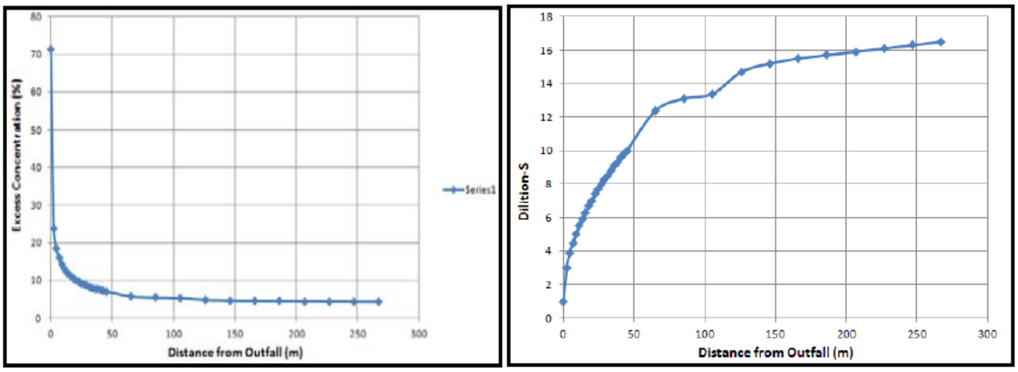


Fig 8. Concentration and dilution variation along the plume centerline.

KATTEB A et al. (2019) [25] Conducted a numerical study for the dilution and dispersion of fouka desalination plant brine effluent marine outfall using CORMIX for near-field area, Delft-3D is used for the far-field mixing area, the results showed that if input data are of high quality to the CORMIX model, it becomes a powerful and reliable management tool for the brine effluent environmental impacts assessment as shown in figs 12 to 15.

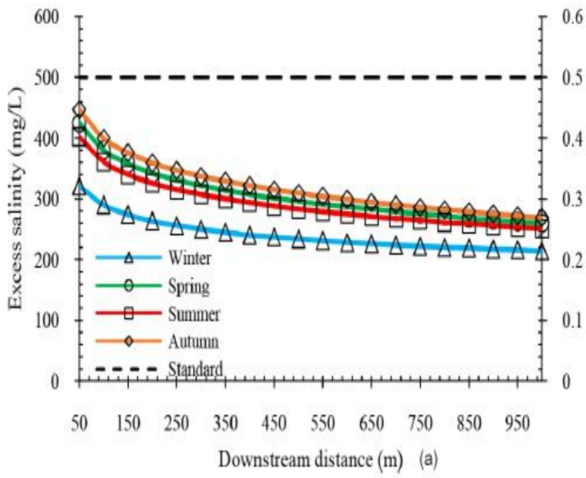


Fig 9. Excess salinity with downstream distance results at RMZ

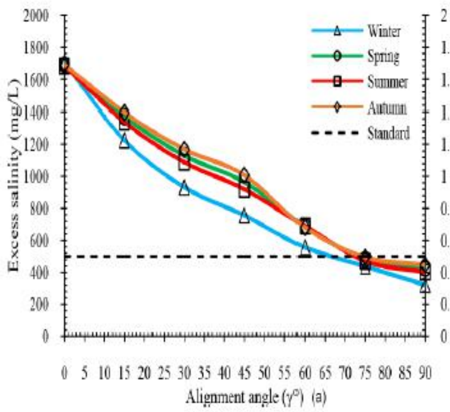


Fig 10. Brine dilution as a function of diffuser alignment angle

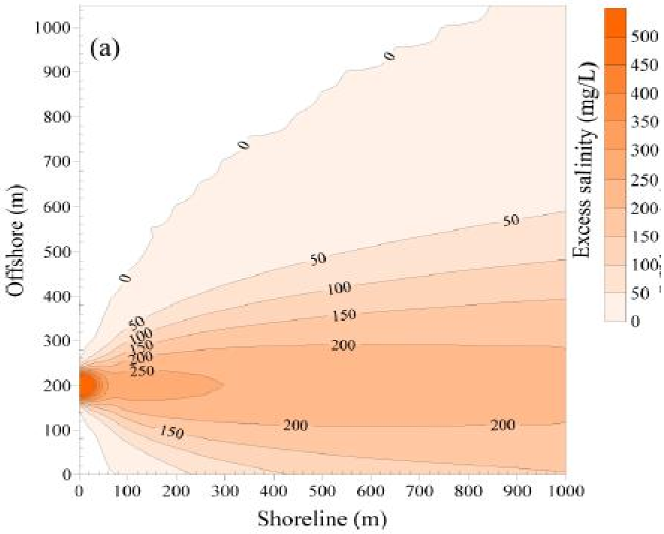


Fig.11. Plume dispersion away from shore line.

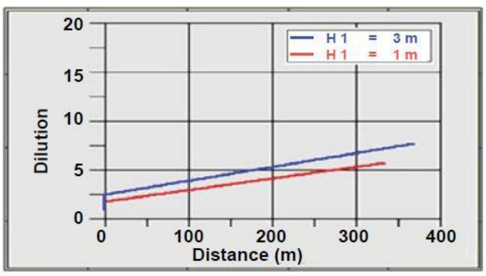


Fig. 12 Dilutions related to different Outfall depth.

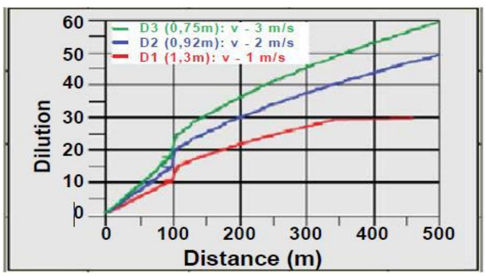


Fig.13 Dilutions with different diameters of diffuser.

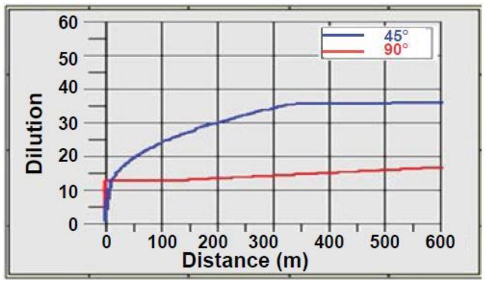


Fig.14 Dilutions related to different Inclination angles.

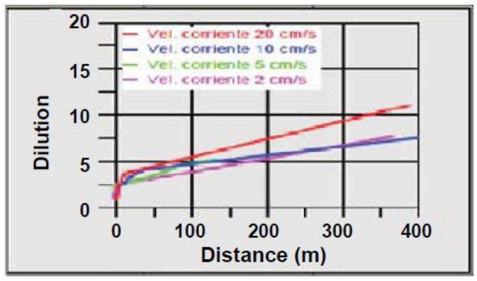


Fig.15 Dilutions according to diffuser different environmental speed values.

Jabel A. Ramirez Naranjo, et al. (2019) [26] Comparative analysis between a venturi-type diffuser and several alternate diffuser installations with CFD simulations have been conducted. Venturi diffusers are currently one of the best existing technologies to reduce the environmental impact of brine in marine environments near discharge points in desalination plants, protecting benthic ecosystems in this way. The CFD is a very valuable computational tool since it allows to simulate the approximate behavior of a fluid in many different conditions, obtaining much information with great ease, and with very reduced costs.

A computational model of this initial design was built and validated with empirical data from the prototypes installed. Subsequently, other state of the art diffuser technologies was simulated with CFD in order to perform a comparative analysis of results. Mixing capacity, effluent dynamics, temperature gradients, density, salinity and dilution were studied.

Preliminary results point to an improvement in the effluent dilution. The use of venturi diffusers in the discharge nozzle causes a change in the behavior of the plume that improves the mixing and dilution processes, compared to the technological alternatives. All of this resulting in environmental benefit.

The physical processes characterizing venturi technology give rise to a typology of effluent plume different and more efficient to those of conventional methods.

III. CONCLUSIONS

The study until now was performed on analyzing and predicting the behavior and the performance of the brine effluent dilution and dispersion. Many researchers conducted a numerical simulation using hydrodynamic models and made a physical model to the outfalls to reach the best dilution and many more. Some questions regarding the outfall length, diameter, the best number of diffuser ports, and design requirements need to exactly solved. The unified design approach of the marine outfall has not achieved yet.

REFERENCES

[1] J.V. Del Benel et all, Ocean brine disposal. Desalination9, 7 (1994) 365-372.

[2] Vlado Malacic (2001) Numerical modelling of the initial spread of sewage from diffusers in the Bay of Piran (northern Adriatic) ecol model 138- 173–191.

[3] Merih Ozcan, Dr. K. Tunc Gokce, Numerical Model (MIKE21) Applications in Outfall Design: Case Study from Turkey. MWWD 2002.

[4] Thomas Hoepner*, Sabine Lattemann (2002), Chemical impacts from seawater desalination plants - a case study of the northern Red Sea. Desalination 152 (2002) 133-140.

[5] Anton Purnama et all, Modeling dispersion of brine waste discharges from a coastal desalination plant. Desalination 15x (2003) 000–000.

[6] Fernández-Torquemada, Y., Sáanchez-Lizaso, J. L., & González- Correa, J. M. 2005. Preliminary results of the monitoring of the brine discharge produced by the SWRO desalination plant of Alicante (SE Spain). Desalination, 182, 395–402.

[7] A.M.O. Mohamed et all (2005), Impact of land disposal of reject brine from desalination plants on soil and groundwater. Desalination 182 (2005) 411–433.

[8] Alameddine, I. and El-Fadel, M. (2007). "Brine Discharge from Desalination Plants: A modeling Approach to an Optimized Outfall design." Desalination, 214: 241-260.

[9] Haibo Niu, et al. Validation of A Buoyant Jet Model (Promise) Against Laboratory Data. 2006.

[10] H.H. Al-Barwani*, Anton Purnama (2007), Evaluating the Effect of Producing Desalinated Seawater on Hypersaline Arabian Gulf. European Journal of Scientific Research 22 No.2 (2008), pp.279-285.

[11] Kikkert, G.A., Davidson, M. J., Nokes, R. I. (2007). Inclined negatively buoyant discharges. J. Hydraulic Eng. 133(5), 545- 554.

[12] Blue Hill Hydraulics Incorporated (2007) Thermal Mixing Zone Analysis and Dilution Study Chesapeake Bay at Calvert Cliffs Nuclear Power Plant, Maryland.

[13] Esperanca Gacia et all (2007), Impact of the brine from a desalination plant on a shallow seagrass (Posidonia Oceanica) meadow Estuarine. Estuarine coastal and shelf scince 72(4):579-590.

[14] Jochen Kämpf, Impacts of blending on dilution of negatively buoyant brine discharge in a shallow tidal sea. Marine Pollution Bulletin 58 (2009) 1032–1038.

[15] A. Etemad-Shahidi, et al. An alternative data driven approach for prediction of thermal discharge initial dilution using tee diffusers. Int. J. Environ. Sci. Tech., 7 (1), 29-36, Winter 2010.

[16] P. Palomar et al. (2012). Near field brine discharge modelling part 1: Analysis of commercial tools Desalination 290 (2012) 14–27.

[17] Hesham El-Badry et al. [42] Hydrodynamic Modeling of the Gulf of Aqaba. Journal of Environmental Protection, 2012, 3, 922-934.

[18] Candela Marco-Méndez, et al. Comparing four mixing zone models with brine discharge measurements from a reverse osmosis desalination plant in Spain. Desalination 286 (2012) 217–224.

[19] Yasser Shawky et all, Environmental and hydraulic design of thermal power plants outfalls ''Case study: Banha Thermal Power Plant, Egypt'' Ain Shams Engineering Journal (2012) 4, 333–342.

[20] Carlos Palacio, et al. Simulation of Near Field Dilution of The Submarine Outfall of Santa Marta (Colombia). Dyna rev.fac.nac.minas vol.80 no.182 Medellín Nov./Dec. 2013.

[21] Sami Maalouf et all, Planning and Design of Desalination Plants Effluent Systems. Desalination 333 (2014) 134–145.

[22] D. V. Salgueiro et all, Modelling the thermal effluent of a near coast power plant (Sines, Portugal). Journal of Integrated Coastal Zone Management, 15(4):533-544 (2015).

[23] Ahmad Rezaee Mazyak et al. (2018) Numerical Simulation of Near Field and Far Field Brine Discharge from Desalination Plants (A Case Study in Persian Gulf). International Journal of Systems Applications, Engineering & Development.

[24] Mazen Abualtayef et al. (2019). Desalination of seawater in the Gaza Strip: the regional short-term low-volume (STLV) seawater desalination plant of Deir Al-Balah as a case study. dwt.2019.23425.

[25] Katteb A et al. (2019) Modelling and Design of Brine Outfall Discharges: Case of A desalination Plant in Mediterranean. Jr. of Industrial Pollution Control 34(1) 1862-1871.

[26] Jabel A. Ramirez Naranjo, et al. Analysis of the Performance of Different Brine Diffuser Technologies with CFD Software. IDAWC 2019.